Bulletin of the Museum of Comparative Zoölogy

AT HARVARD COLLEGE.

Vol. LVIII. No. 4.

NOTES ON THE ONTOGENY OF PARADOXIDES, WITH THE DESCRIPTION OF A NEW SPECIES FROM BRAINTREE, MASS.

By Percy E. Raymond.

With One Plate.

CAMBRIDGE, MASS., U. S. A.:

PRINTED FOR THE MUSEUM.

April, 1914.

No. 4.— *Notes on the ontogeny of Paradoxides, with the description of a new species from Braintree, Mass.*

By Percy E. Raymond.

Paradoxides *harlani* is so large and striking a fossil, its occurrence is such an oasis in the sterility of Massachusetts palaeontology, and its discovery and subsequent history borders so closely upon the domain of romance, that it has become one of the most widely known of all the older invertebrate fossils. Although repeatedly described and figured and known from abundant material, the species has never been studied from the phylogenetic standpoint, and it has not, therefore, been brought out how strikingly different this species really is from most of the other members of the genus. In studying the specimens from the viewpoint of an investigation of the growth stages and relationship to other forms, the writer has been forced to the conclusion that there are really two species present in the Hayward quarry at Braintree, and the new species is now named in honor of the Messrs. Hayward, father and son, who have long been proprietors of the quarry which has furnished these trilobites, and who have served science by the care with which they have conserved good specimens.

Paradoxides harlani Green.

Plate, fig. 3–6.

Paradoxides harlani Green, Amer. journ. sci., 1834, **25**, p. 336. W. B. Rogers, Proc. Boston soc. nat. hist., 1856, **6**, p. 27–29, 40–44. Stodder, Ibidem, p. 369. W. B. Rogers, Amer. journ. sci., 1856, ser. 2, **22**, p. 296, Edinb. New philos. jour., 1856, new series, **4**, p. 301; 1857, **6**, p. 314. C. T. Jackson, Comptes rend. Acad. sci. Paris, 1856, **43**, p. 883; 1858, **46**, p. 254, Proc. Boston soc. nat. hist., 1859, **7**, p. 54, 75. W. B. Rogers, Ibidem, p. 86. Ordway, Ibidem, 1860, **7**, p. 427, 1861, **8**, p. 1–5, fig. 2. C. T. Jackson, Ibidem, p. 58. Dana, Man. geol., 1863, p. 189, fig. 245. Walcott, Bull. 10, U. S. geol. surv., 1884, p. 45, pl. 7, fig. 3; pl. 8, fig. 1b, c, e, (non 1, 1a, 1d); pl. 9, fig. 1. Grabau, Occ. papers Boston soc. nat. hist., 1900, **4**, p. 681, pl. 35, fig. 3 (after Walcott); pl. 36 (the type); pl. 37; pl. 38, fig. 1b, c, e; non 1, 1a, 1d (after Walcott); pl. 39 (after Walcott). Shimer, Amer. journ. sci., 1907, ser. 4, **24**, p. 178. Walcott, Smithsonian misc. coll., 1910, **53**, p. 254, fig. 12, 13, (non 10, 11).

Paradoxides spinosus W. B. Rogers, Geol. Penn., 1858, **2**, p. 816, fig. 590. Barrande, Bull. Soc. geol. France, 1860, **17**, p. 551; Proc. Boston soc. nat. hist., 1860, **7**, p. 369.

This species has often been described and is too well known to require any formal description here; but I wish to emphasize certain features which, while now recognized, really have more importance than has previously been ascribed to them. As seen by the references cited above, Barrande considered *P. harlani* as identical with the Bohemian *P. spinosus*. This identification was immediately controverted by Ordway, and later writers have not accepted it; but of the two really vital differences of *P. harlani* from *P. spinosus* and most other species, only one has ever received attention. Ford (Amer. journ. sci., 1881, ser. 3, **22**, p. 250) has called attention to the fact that the species of Paradoxides may be divided into two groups, in one of which the second segment of the thorax is always prolonged beyond the others, while in the other group the second segment is in no way distinguishable from the others. To the first group belong the Bohemian and South European species, while the Scandinavian, British, and American forms belong to the second group. *Paradoxides spinosus* has the second segment extended, while *P. harlani* has not.

The second feature in which *P. harlani* differs from other species, and one which makes it almost unique, is the wide, depressed brim at the anterior end of the cranidium. Of the forty-six recognizable species of Paradoxides whose cranidium is known, only four, *Paradoxides bennetti* Salter, *P. groomi* Lapworth, *P. regina* Matthew, and *P. harlani* Green have a rimless brim (though there is a possible fifth, *P. brachyrhachis* Linnarsson). Of these, only two, *P. harlani* and *P. regina* have a wide brim in front of the glabella. All other species of Paradoxides described from adult specimens have the glabella reaching nearly or quite to the anterior margin.

Among the numerous cranidia obtained from the Paradoxides beds at Braintree, there are some of the smaller ones which have a rim on the front of the cranidium, and the front of the glabella almost reaches the rim. These specimens have been considered by previous writers to be the young of *P. harlani*, and it was believed that in later stages of growth the anterior part of the cranidium became widened and flattened. Specimens recently obtained by the writer from Mr. Hayward's collection show that this could not have been the case, for there are specimens of the broad brimmed type which are of the same size or smaller than some of those showing the rim. The rimmed

forms must therefore belong to another species, which is here described as *P. haywardi*. The largest cranidium of the rimmed form obtained is 35 mm. long, while the smallest cranidium with the brim and no rim is 19 mm. long (M. C. Z., No. 22, Pl., fig. 3). On this specimen the part of the brim in front of the glabella is 2.25 mm. wide, or nearly 12% of the total length. On a specimen 34 mm. long it is 4.5 mm. long, or 13%, while on a large cranidium, 103 mm. long, it is 12 mm. wide, or 11%. On the numerous cranidia between the smallest and largest it varies from 10% to 13% of the length, showing that while it grows wider during the growth of the individual, it is relatively about the same width in all cranidia above 19 mm. long. What it might be in smaller specimens we have as yet no means of knowing.

The significance of this wide brim on the cranidium of *P. harlani* is best appreciated after studying the ontogeny of Paradoxides.

Ontogeny of Paradoxides.

The smallest specimen of Paradoxides known is that described by Barrande as *Hydrocephalus saturnoides* (Systeme Silurien du centre de la Bohême, 1852, 1, p. 380, pl. 49). This specimen is slightly over 1 mm. long, the cephalon is oval, and makes up five sixths of the total length. The glabella is large, oval, makes up most of the cephalon, extends to the front of the head, and has no glabella furrows, though there is a median longitudinal furrow. The palpebral lobes form the lateral margins of the cephalon, but judging from the appearance of the cranidium, the free cheeks would have been present even at this early stage, had the specimens been complete. The occipital segment is prominently set off from the rest of the cephalon, and extends to the long, intergenal spines which cross it at right angles. One thoracic segment and a pygidium are present. From the inferred presence of the free cheeks and the presence of a thoracic segment, it is evident that this is not a protaspis, but that several moults have already taken place.

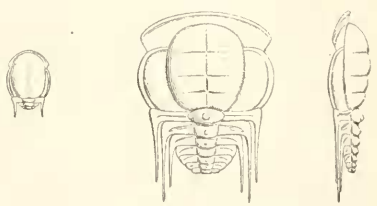

Fig. 1.— *Hydrocephalus saturnoides*, showing two of the stages of development. After Barrande. Note the wide, oval glabella. Compare with Plate, fig. 9.

The second specimen described by Barrande is 1.33 mm. long, the

cephalon occupying three fourths of the length and the thorax and pygidium one fourth. The thorax contains three segments. The cephalon has three glabellar furrows which cross the entire glabella. Three more stages of development are illustrated by Barrande, in the last of which the test is about 2 mm. long, the cephalon being a little over 1. mm. In the third, fourth, and fifth stages the first two segments of the thorax bear backward-directed spines and the intergenal spines are still present. The most conspicuous feature of the cephalon in stage five is the presence of a narrow, smooth, flat brim on the front of the cranidium. This is first seen in stage four and becomes wider in stage five. The three glabellar furrows and the median longitudinal furrow are still present at stage five, but the median furrow is not so conspicuous as in the smaller specimens.

The ontogeny of Olenellus indicates that the palpebral lobes are formed by the recurved pleura of the second glabellar lobes. It is very important to note that in these specimens known as *Hydrocephalus saturnoides* the anterior ends of the palpebral lobes join the glabella in front of the anterior glabellar furrows, thus indicating that the furrows present are 2, 3, and 4. Beyond stage five Barrande did not trace any line, but the writer believes that *Paradoxides orphanus* and *P. pusillus* represent the next stages of this same species. In the M. C. Z. there is a cranidium 1.5 mm. long, identified as *P. pusillus*, but answering better to the description of *P. orphanus*, which in some measure fills the gap between the largest of Barrande's figured specimens of *H. saturnoides* and the smallest of his *P. orphanus* and *P. pusillus*. In this specimen the anterior brim is narrow, occupying about the same proportion of the whole length as is shown in Barrande's figure of *P. orphanus*. Glabellar furrows 2, 3, and 4 all cross the whole glabella, as in *H. saturnoides* instead of 3 and 4 only, as in *P. pusillus*, but the connection between the two sides on furrow 2 is quite shallow. This specimen, moreover, adds another pair of furrows at the sides just in front of the palpebral lobes, as in *P. pusillus*. From this specimen to a typical *pusillus* with a wide brim, the collection contains all stages, so there is no doubt of the connection in that direction. Barrande has figured (*Loc. cit.*, 1872, **1**, suppl. pl. 9, fig. 22, 23), an entire specimen of *P. pusillus* 2.5 mm. long, the cephalon of which makes up 55% of the length. Seven free segments are present, and the pygidium contains three or four more. The cephalon has a wide brim, 23% of the whole length, and there are no intergenal spines present, though the first two segments of the thorax have long spines, the spines of the second being longer than the first.

In the M. C. Z. there is a complete specimen of *P. "pusillus"* which is 4.5 mm. long, or about twice as large as the one figured by Barrande. The cephalon is 2 mm. long, or 44% of the whole length, and the brim is narrower than in the last specimen. Both the genal spines and those of the second thoracic segment are long, but the first thoracic segment has lost its spines. There are about fifteen thoracic segments ending in free spines, but those back of the tenth are crowded into an extremely small space. (See Plate, fig. 9).

The largest cranidium of *P. pusillus* in the collection is 4.5 mm. long, and Barrande does not mention any larger. In this largest specimen the brim is only .5 mm. wide, thus occupying but 13% of the length, showing that with increase in size the brim is becoming shortened again. Furrows 3 and 4 cross the glabella, while 2 does not. Furrow 1 is present and distinct at the sides.

Next to this specimen stands our smallest cranidium of *P. rugulosus* Hawle and Corda, which is 4 mm. long and practically identical with the largest of *P. pusillus*, but furrows 2 are a little more faint, furrows 4 turn more obliquely backward, and the posterior ends of the palpebral lobes are a little closer to the glabella. From this small specimen we have all gradations up to a full-grown *P. rugulosus* with a cranidium 27 mm. long. In the adult *P. rugulosus* the anterior furrow is very narrow, the glabella being almost in contact with the rim.

Whether this line of development is based entirely upon one species or not, the fact remains that in the development of the brim of Paradoxides there is a change from the very youngest where there is no brim to a youthful stage where the brim is wide, then back to a later adult stage in which the brim is again diminished almost to nothing. In the matter of the brim, therefore, *P. harlani* retains at maturity a youthful characteristic, lost in *P. rugulosus* when less than 10 mm. long.

There is a certain amount of evidence that the line traced above from *Hydrocephalus saturnoides* through *Paradoxides orphanus* and *P. pusillus* to *P. rugulosus* represents the growth stages of one species. There are in the collections at the M. C. Z. specimens in all stages between *P. pusillus* and the adult *P. rugulosus*, and the only sharp break is between the largest specimen of *Hydrocephalus saturnoides* and the smallest of *P. orphanus* or *P. pusillus*. In the matter of the brim there is no break, for we see it gradually becoming wider and wider in specimens of *H. saturnoides*, it continues getting wider in *P. orphanus* and *P. pusillus* up to a certain stage, then decreases in width in the larger *pusillus* and the young of *rugulosus*. The only great change between

Hydrocephalus saturnoides and *P. orphanus* is the introduction just at this point of the anterior pair of glabellar furrows and the reduction in size of the glabella. But the furrows come in where we would have predicted them, just in front of the palpebral lobes. And this brings out a point, which was wholly unexpected, that in this species of Paradoxides the glabella of the youngest specimens known is smooth and unsegmented, and gains its furrows during growth. This will be referred to again later.

There are also external indications which indicated that the above series may be a natural one. *Hydrocephalus saturnoides, P. orphanus,* and *P. pusillus* all palpably represent immature individuals and have been generally so considered. Hydrocephalus was placed by Barrande as akin to Paradoxides, and by Beecher was referred to that genus. Barrande separated it from Paradoxides, first, on account of the course of the facial suture, which left the genal spine on the fixed instead of the free cheeks; second, on account of the longitudinal furrow on the glabella; and third, because of the few thoracic segments, there never being more than twelve.

The third characteristic merely indicates immature specimens and need not be considered. In regard to the second one of the remarkable features of *P harlani* is that this same longitudinal furrow of the glabella is present, at least as a line of weakness, in very large specimens. As to the first, the spines on the fixed cheeks are merely the terminal spines of the palpebral lobes, the intergenal or "interocular" spines known also in the young of Olenellus. From the form of the cranidium it is evident that entire specimens had free cheeks, and they doubtless bore the true genal spines. There is, therefore, no reason for separating Hydrocephalus from Paradoxides.

In regard to occurrence, all four species come from the Cambrian band in the vicinity of Skrey, and so far as known are found together in the same beds. Most of the specimens of *H. saturnoides* in the M. C. Z. collection are from Teirovic, from which locality there are also specimens of *P. pusillus* and *P. rugulosus.* All are in the same kind of matrix and have the same sort of preservation. At Slap, where *P. rugulosus* is most abundant, *H. saturnoides* seems less common, though *P. pusillus* is quite common.

Of the Bohemian species, *P. sacheri* Barrande, *P. lyelli* Barrande, *P. bohemicus* (Boeck), and *P. rotundatus* Barrande seem to be confined to the Ginetz band of the Cambrian, hence it is unlikely that these young should belong to any of those species. *Paradoxides spinosus* (Boeck) is very common in the band of Skrey and when I began to

study these specimens, I supposed them to be the young of that species. That they do not belong to that species is, however, shown convincingly by the eyes. The adult of *P. rugulosus* has the palpebral lobes touching the glabella at their anterior ends and reaching the occipital furrow behind, while in the adult of *P. spinosus* the eye is much shorter, and does not reach either the glabella or the occipital furrow. Barrande has figured (*Loc. cit.*, pl. 12, fig. 7) a specimen of *P. spinosus* with a glabella 4.5 mm. long in which the eyes have the same position as in the adult, while in the Museum series, specimens this size have the *rugulosus* type of long eyes. The thorax of *P. pusillus* is of the *spinosus* rather than the *rugulosus* type, but that is a character which might change readily during growth from a size of 4 mm. up to the size of the adult *P. rugulosus*. It is, however, possible that the young of the two species would be, in the earliest stages, indistinguishable.

Young Specimens of Paradoxides.

Bohemia.

Hydrocephalus carens Barrande and *Paradoxides inflatus* Corda make a short series showing the early growth stages of some as yet unidentified species. Barrande figures nine stages in the growth of *H. carens*, the smallest specimen being 2 mm. long and the largest 4 mm. The thorax and pygidium together show three segments in the smallest

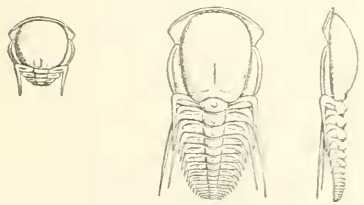

Fig. 2.

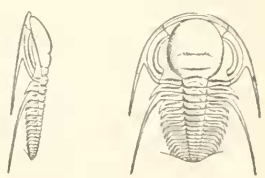

Fig. 3.

Fig. 2.— *Hydrocephalus carens* Barrande. After Barrande. This series shows two stages in the development. Compare with Plate, fig. 3.
Fig. 3.— *Paradoxides inflatus* Corda. After Barrande.

and fifteen in the largest. The glabella is almost circular and shows no glabellar furrows in the first four stages described, and only No. 4 is present in the last five. Intergenal spines are present on all, and on specimens 6–9 the first two segments of the thorax have terminal

spines, those of the first segment being the longer. Barrande figures an entire specimen of *P. inflatus* Corda, 5 mm. long, which differs from *H. carens* only in possessing free cheeks, glabellar furrow No. 3, and in having the terminal spines of the first thoracic segment reduced to normal, while the second pair have increased in length. Into what species this form finally developed there is no way of determining without more material. It is interesting to note, however, that the development agrees with the series described above in that the glabella is first smooth, and the glabellar furrows are added during the nepionic stages. They seem to be greatly retarded in this form, as only two furrows (Nos. 3 and 4) have been formed in the largest specimen figured by Barrande. It may be noted that in this form, as in *Hydrocephalus saturnoides*, the brim on the cranidium widens constantly during the known stage of growth, though it never achieves any great width. The M. C. Z., contains a single specimen of *P. inflatus* (No. 651) about 5 mm. long from Velka in the Cambrian band of Ginetz. All the other specimens recorded have come from the band of Skrey, but that it does occur in the more southern band suggests that it may possibly be the young of some form which in the adult has only two pairs of glabellar furrows, possibly *P. bohemicus* (Boeck).

The M. C. Z. contains a single minute specimen (No. 33) 1 mm. long of a young "Hydrocephalus" which is in many respects quite unlike *H. saturnoides*. (Plate, fig. 8). The specimen differs from that form in having the glabella narrow, expanding forward. The occipital ring and furrow are well marked, the glabellar furrows 2, 3, and 4 are deeply impressed, extend across the glabella and divide it into ring-like lobes. The anterior lobe, which is composed of lobes 1 and 2, is transversely oval, and nearly twice as wide as that portion of the glabella back of it. Furrows 1 are faintly indicated, and the frontal lobe has a deep longitudinal furrow which does not reach lobe 3. The palpebral lobes are long, and extend into spines behind the occipital segment. The brim is narrow, and the truncation at the sides is so slight that it is doubtful if free cheeks were present. This specimen is about the size of the smallest specimen of *H. saturnoides*, and it does not seem that it could represent a younger stage in the development of that species, but it appears probable that it is the protaspis of another form. From the outline of the posterior end of the specimen, it seems probable that it is complete, and that the small posterior projection represents the proto-pygidium.

The young specimen of *P. spinosus* figured by Barrande has already been alluded to. Its chief interest lies in the fact that so small a

specimen, only 11 mm. long, should be so like the adult. The chief differences are that the eyes are slightly longer, the genal spines arise further forward on the head, and the terminal spines of the second thoracic segment are much longer. These terminal spines of the second segment seem the most persistent of the juvenile characters, and as has already been stated, all the Bohemian species have some remnant of these spines in the adult stage.

The youngest specimen of *P. bohemicus* yet seen is that figured by Barrande (*Loc. cit.*, pl. 10, fig. 25). It is 14 mm. long, not including spines, and exhibits only two youthful characteristics. The eyes are long, and the terminal spines of the second thoracic segment are greatly prolonged. The glabella shows only two furrows (Nos. 3 and 4) the same as in the adult.

Outside Bohemia young Paradoxides are evidently exceedingly rare and have been figured only incidentally. Nothing except a few cranidia seems to have been found.

Scandinavia.

The youngest Scandinavian specimen known is that figured by Linnarsson as the type of his species *P. aculeatus*. This is a cranidium slightly less than 2 mm. long from the *Paradoxides oelandicus* zone of Borgholm. There is a relatively wide brim in front of the glabella, the palpebral lobes extend from the second glabellar lobes to the posterior margin, intergenal spines are present, the glabella is long and narrow, expands slightly forward and has four pairs of glabellar furrows. It resembles a young Paradoxides more than *Hydrocephalus saturnoides* does, as the glabella is of a more normal shape. This specimen [1] is probably the young of either *P. sjogreni* or *P. oelandicus*, more likely of the former, as Linnarsson figures another small cranidium 5.5 mm. long which he refers to that species, though with doubt. This latter specimen also has a wide brim and four pairs of furrows. The adults of both *P. sjogreni* and *P. oelandicus* have a narrow border, and the glabella almost touches the rim.

Great Britain.

Salter figures (Quart. journ. geol. soc., 1869, **25**, pl. 3, fig. 8–10) three young specimens of *Paradoxides hicksi*. These specimens are

[1] Lindstroem considers this the young of *P. oelandicus*. K. Svensk. vet.-akad. Handl., 1901, **34**, no. 8, p. 17.

young cranidia in the *pusillus* stage. They have four pairs of glabellar furrows, long eyes, and a wide brim. The adult has four pairs of furrows, short eyes well forward, and no brim. Hicks, in the description, says of these specimens: — "In the young the margin is equal all around, and a considerable space, also, separates the glabella from the anterior margin. This space gradually diminishes as the individual grows; and the glabella enlarges until, as in the fully grown species, the margin becomes fully obliterated."

America.

Paradoxides tenellus Billings from Newfoundland is another form described from a young specimen in the *pusillus* stage. The typical cranidium is 6 mm. long, shows four pairs of furrows on the glabella, has long palpebral lobes and a wide brim. This species may possibly be the young of *P. decorus*, a very imperfectly known species which Billings describes from a cranidium about 26 mm. long, and which has four pairs of furrows, but has the glabella in contact with the rim. It occurs in the same locality as *P. tenellus*.

Matthew presents notes on the young of *P. eteminicus* and *P. acadius*, and figures three specimens of these species in the *pusillus* stage. All have wide brims, long palpebral lobes, and four pairs of furrows. They are the young of forms whose glabellas nearly or quite touch the anterior rim, and which retain the four pairs of furrows and long palpebral lobes at maturity.

Summary on Ontogeny.

From the above survey of the material now available for the study of the ontogeny of Paradoxides, we see that the youngest shell or protaspis is very similar to that of Olenellus. The glabella in the youngest specimens of both species of "Hydrocephalus" is specialized and unlike that of any other trilobite of which the young is known, in that it occupies a large part of the head, is very wide, and bears no transverse furrows. The first furrow to appear is a median longitudinal one, which is obliterated at an early stage. Glabellar furrows are introduced in young stages, and in later stages of development there seems to be no reduction of furrows by their obliteration successively from the front backward, such as is seen in some of the later trilobites. The glabella occupies the whole length of the cranidium

in the youngest stages known, becomes proportionately shorter during some of the early nepionic stages (*pusillus* stages), and becomes longer again in the neanic and early ephebic stages. The palpebral lobes are in general very much longer in young stages than in later ones, but many species are primitive in this regard, and retain the long eyes at maturity (*P. rugulosus* group). Most of the adult characteristics are assumed at an early age, so that specimens 6–10 mm. long are often almost identical in form with the adult; but certain minor features such as the lateral extention of the second thoracic segment, persist well on into the ephebic stages.

Application to P. harlani. It will now be seen why the form of the brim of this species is so important. The wide brim is a feature which, in this genus, is decidedly larval in character, and in such forms as are known to have had it, it is lost at an early age, when the cephalon was 6–10 mm. long. Its retention in large adults like *P. harlani* is most unusual. Another result arrived at above is applicable to *P. harlani.* It was found that the glabellar furrows were not lost by the adult, but that, on the contrary, the adult had more furrows than the young. None of the very young of *P. harlani* are known, but the smallest glabellas now before us (11 mm. long) show two pairs of furrows which cross the glabella and another pair, (No. 2), which are faintly indicated at the sides. The small cranidium figured (Plate, fig. 3) which is 19 mm. long, shows a similar condition, but the No. 2 furrows are much more distinct. In some of the largest specimens (glabella 100 mm. long) furrows 1 and 2 are both distinct, and most specimens with cranidia more than 40 mm. long show all four pairs of furrows. In these two features, then, the wide brim and the slow acquisition of glabellar furrows this species is very primitive.

The palpebral lobes in the smallest specimen mentioned above reach from the glabella back to the occipital furrow, and their chord is 6 mm. in length. In specimen No. 22 they meet the glabella, but terminate 1 mm. in front of the occipital furrow, and the chord of the lobe is 7 mm. In the adult this eye is proportionately much smaller, for, on a cranidium 79 mm. long the posterior end of the lobe is 9 mm. from the occipital furrow and 8 mm. from the glabella, the chord of the lobe being 21 mm. Thus the proportion of the length of the chord of the palpebral lobe to the length of the cranidium in the smallest specimen is .50, in the second, .32, and in the adult, .26, or a reduction of about one half. In common with most other species of Paradoxides, *P. harlani* shows a great lateral extension of the fixed cheeks during the process of growth.

Eight of the largest cranidia in the collection, varying from 60 to 120 mm. long, show a longitudinal cracking along the median line which strongly recalls the median longitudinal furrow of Hydrocephalus. In this case it is not exactly a furrow, but the crushing along this line of so many specimens indicates a line of weakness here. The backward or forward turning of the third and fourth furrows of the glabella at the median line in so many species is also probably to be connected with this furrow.

Comparison with other Species.

As mentioned above, there are only a few rimless species of Paradoxides, and it is with such forms alone that *P. harlani* can be compared. It has been compared most commonly with *P. spinosus* (Boeck); but from that species it differs, not only in the possession of a rimless brim and the absence of the terminal spines on the second thoracic segment, but also in the pygidium, which in *P. harlani* is larger and longer and has a much longer axial lobe than the Bohemian species.

The species which lack the rim, besides *P. harlani*, are *P. bennetti* Salter, *P. groomi* Lapworth, and *P. regina* Matthew. *P. bennetti* is very similar to *P. harlani* in the shape of the glabella, the possession of four pairs of glabellar furrows, and medium sized eyes. The genal spines appear to be shorter, and according to the single specimen in the M. C. Z., the brim is not so wide. In this specimen, the second segment does not seem to be enlarged as indicated by Salter and mentioned by Ford, but is actually smaller than the first.

Paradoxides groomi is known only from fragments which indicate a species similar to *P. harlani*, but with narrower thorax and, according to Cobbold's description, shorter fixed cheeks.

The principal differences between *P. regina* Matthew and *P. harlani* seems to lie in the pygidium, which is more quadrangular in outline and has a shorter axial lobe in the former species than in the latter. Outside the pygidium it is, as has been pointed out by Grabau, exceedingly difficult to point out differences between the two species. The majority of specimens of *P. harlani* have a narrower cephalon and glabella than the Acadian form, but as Grabau has already shown in his table of measurements, we have specimens of a wide form which correspond very closely to the dimensions of Dr. Matthew's specimen. Incidentally I might mention that the Geological section of the M. C. Z. has recently acquired a specimen of *P. harlani* with a cranidium 138

mm. long, or 18 mm. longer than the cranidium of Dr. Matthew's specimen of *P. regina*. This, restored on the basis of the dimensions of the wide form, would exceed both in width and length the *P. regina;* but, unfortunately it appears to belong to the narrow type, and would therfore cover considerably less area than that species.

Paradoxides haywardi sp. nov.

Plate, fig. 1, 2, 7.

Paradoxides harlani Walcott, *partim*, Bull. 10, U. S. geol. surv., 1884, pl. 8, figs, 1, 1a, 1d.

Among the many cranidia which have been collected at the Hayward quarry at Braintree there are a number which at the anterior end differ markedly from *Paradoxides harlani*. Instead of having a flattened rimless brim, they have an elevated striated marginal rim separated from the glabella by a narrow furrow. Moreover, the outline of the margin of the anterior end of the cranidium, instead of being a smooth curve as in *P. harlani*, is obtusely pointed, the two segments of the rim being straight and meeting at an angle of about 150° in front of the axial line of the glabella. The glabella is convex, semicircular in front, widest opposite the anterior ends of the palpebral lobes. The dorsal furrows are strongly marked and come together in front of the glabella. No specimen so far seen shows any traces of glabellar furrows No. 1, and No. 2 when present, are only slightly impressed and do not show at all in most specimens. No. 3 are quite strong but usually do not meet at the centre, though in one or two specimens they appear to. No. 4 extend across the glabella. The occipital ring is wide and bears a small median tubercle. The eyes are of medium size for the genus. The palpebral lobe does not reach the occipital furrow behind, nor is it connected with the glabella at the front.

No free cheek has been seen which can be assigned with certainty to this species. Free checks seem to be less common than any other parts of trilobites at the Braintree locality.

One specimen in the collection shows a part of a thorax still connected with a cranidium, though the body is partially shoved under the head. Eleven segments are present. The axial lobe is about one third the total width, and the pleura are marked by wide grooves which cross them diagonally, the grooves extending out to

the point where the pleura begin to taper into spines. These grooves occupy a much larger proportion of each pleuron than do those of *P. harlani*. The terminal spines appear to be rather longer and more slender than in *P. harlani*. The second spine is not longer than the others.

The pygidium differs strikingly from that of *P. harlani*, and is the one figured by Walcott (*Loc. cit.*, pl. 8, fig. 1d). This pygidium differs from the one found on entire specimens of *P. harlani* in being broader than long, and in having the axial lobe distinctly rounded instead of triangular. The last five segments of this specimen (M. C. Z. No. 20) are much longer than those on the average specimen of *P. harlani*, and it is seen from the small entire specimen in the collection of Mr. W. P. Haynes that it belongs to *P. haywardi*. A second pygidium of this type is in the M. C. Z. (No. 652) and a third in the Geological section of the M. C. Z. A nearly entire specimen which is in the collection of Mr. Winthrop P. Haynes has seventeen thoracic segments and shows that the short pygidium assigned above to this species really belongs to it. Mr. Haynes's specimen is largely exfoliated, and the substance of the pygidium is entirely gone. Its outline is, however, indicated on the matrix, and it is of the broad short type, apparently 9 mm. long and 15 mm. broad. The whole trilobite is about 105 mm. long and is quite narrow, the thorax being about 55 mm. wide at the first segment.

Types.— As the holotype of this species I have selected cranidium No. 16 (Plate, fig. 1) recently presented to the M. C. Z. by Mr. Lemuel Hayward. The left side of this cranidium is very well preserved, but the right side is broken and the broken piece partially thrust under the glabella. Furrow 3 is distorted.

As paratypes I have selected specimens Nos. 17, and 18, both of which are illustrated. All are in the M. C. Z.

Measurements. Holotype.— Cranidium 35 mm. long; glabella 31 mm. long, 23 mm. wide at front of eyes; chord of palpebral lobe 13 mm. long; rim 2 mm. wide at front of glabella, 4 mm. wide at corner of cranidium.

Paratypes.— No. 17. Cranidium 32 mm. long; glabella 30 mm. long, 22 mm. wide at front of eyes.

No. 18. Cranidium and eleven thoracic segments, 76 mm. long as it stands, but as some segments are pushed under the head, the actual length was probably about 80 mm.; width of axial lobe at 2d segment 20 mm.; total width of thorax, not including terminal spines, 58 mm.

Remarks.

As may be seen by the following quotation, the specimens here separated as a new species have not escaped observation. Dr. Walcott (*Loc. cit.*, p. 46), in discussing the broad and narrow forms of *P. harlani* says:—"In the head the greatest variation is seen in the contour of the frontal margin, and the gradual development of the frontal limb and rim. On the smallest specimens the frontal limb is very short and more or less rounded. With the increase in size, the space between the glabella and the marginal rim increases in width, and the latter broadens and flattens out." It is not the narrow form of *P. harlani* as described by Walcott and Grabau which I am separating as a new species, but the form with the narrow brim and raised, striated rim. Judging from the above quotation, this form has been placed as the young of the narrow form of *P. harlani*. As has been shown under the description of *P. harlani* above, material recently collected shows that the young of *P. harlani* had a broad flat rimless brim, similar to that of the adult, so that the rimmed forms can not be referred to that species.

Comparison with other Species.

Paradoxides haywardi is a much more normal type of Paradoxides than *P. harlani*, and it is therefore comparable to a far greater number of species. From *P. harlani* itself, it differs, as has already been pointed out, in having an angular instead of a rounded frontal margin, and in having a narrow brim and thickened rim on the front of the cranidium, in the absence of the anterior pair of glabellar furrows, and probably in the wider furrows and narrower spines on the pleura of the thorax. It resembles *P. eteminicus* Matthew more closely than any other American form, but differs from that species in having shorter eyes, the lobes of which do not touch the glabella or neck ring, in lacking the anterior pair of glabellar furrows, and in having a wider groove separating the glabella from the rim. Most of these same differences and others obtain between *P. abenacus* Matthew, *P. acadius* Matthew, *P. micmac* Hartt, *P. lamellatus* Hartt, and *P. haywardi*. *P. regina* Matthew and *P. bennetti* Salter appear to have the wide margin of *P. harlani;* and of Billings's two Newfoundland species, *P. tenellus* seems to be based on immature specimens, and *P. decorus* is not well known.

Of the numerous British species, *P. aurora* Salter, *P. hicksi* Salter, and *P. forchhammeri* Angelin have the glabella reaching on to the rim, *P. davidis* is of the *P. tessini* type with the elongated terminal spines of the pleura, as is also, presumably, *P. bohemicus salopiensis* Cobbold, of which the thorax is not known. *P. groomi* Lapworth is of the *P. harlani* type, *P. harknessi* Hicks agrees with the new species in the presence of a furrow between the glabella and rim, but the eye lobes are much longer and more narrow, and the glabella is narrower and retains the first pair of furrows. *P. intermedius* Cobbold is quite similar in form of glabella, groove and rim, to *P. haywardi*, but the palpebral lobes are too long and reach both the neck ring and the glabella. The *Paradoxides rugulosus* Hawle and Corda, Cobbold, also has the long eye lobes and the first pair of glabellar furrows, and, moreover, differs from the true *rugulosus* in lacking the furrow which should separate the glabella from the rim.

Turning now to the Scandinavian species, we find that *P. forchhammeri* Angelin, *P. hicksi palpebrosus* Linnarsson, *P. oelandicus* Sjogren, and *P. tumidus* Angelin all have the glabella reaching the rim, and most of them have other features in which they differ strikingly from *P. haywardi*, while *P. affinis* Angelin, and *P. tessini* Brongniart and its varieties of course have the long terminal spines on the pleura. *P. tuberculatus* Angelin is known only from a fragment which has a large tubercle on the fixed cheek opposite the basal lobes of the glabella. *P. brachyrhachis* Linnarsson appears to be a rimless species with four pairs of glabellar furrows, and so comparable to *P. harlani*, while *P. aculeatus* is based on a very immature specimen. There is, therefore, no Scandinavian species very closely allied to *P. haywardi*.

Of the Bohemian species, *P. bohemicus* (Boeck) is quickly eliminated because in the adult the glabella reaches the rim and the terminal segments of the pleura are elongated. *P. desideratus* is probably not a Paradoxides, but possibly an Albertella, and *P. expectans* also is doubtfully a Paradoxides. *P. imperialis* is known only from a fragment of the thorax, while *P. inflatus* Corda, *P. pusillus* Barrande, and *P. orphanus* Barrande are evidently based on very immature specimens. *P. spinosus* and *P. rotundatus* Barrande both have glabellas which in the adult touch the anterior rim and retain all four pairs of furrows in most cases. *P. rugulosus* and *P. sacheri* both have the groove in front of the glabella, but *P. rugulosus* has very long eye lobes, touching the glabella and occipital ring, while *P. sacheri* has very short diagonal furrows and very curving spines on the thorax. *P. lyelli* has a long narrow glabella which touches the marginal rim.

Only a few forms are known from southern Europe (Spain, France, Sardinia). *P. asper* Bornemann is founded on fragments and its right to be called a Paradoxides is queried by Pompeckj. *P. mediterraneus* Pompeckj is very similar to *P. rugulosus*,—was so identified by Bergeron,—and the cephalon is therefore similar to that of *P. haywardi*. *P. barrandei* Barrois has the whole four pairs of glabellar furrows and the glabella touches the marginal rim, but *P. prodoanus* de Verneuil and Barrande, which is very similar, has a narrow furrow between the glabella and rim, but the eyes are very close to the glabella, their anterior ends touch it, and the posterior ends also curve in unusually close to the glabella.

It appears then that *P. haywardi* is most closely allied to *P. eteminicus* Matthew of the St. John area in New Brunswick, *P. intermedius* Cobbold from Comley in Stropshire, England, and *P. rugulosus* Hawle and Corda, and *P. mediterraneus* Pompeckj of central and southern Europe. These four species, so far as they are known, all seem to belong to the *P. rugulosus* group in which the eye lobes are very long, the glabella is separated from the marginal rim by a furrow (*P. eteminicus* has a very narrow furrow) and have a rather long pygidium, the posterior margin of which is straight or concave in outline (the pygidium of *P. intermedius* is an exception). The eyes of *P. haywardi* are not of the *P. rugulosus* type, nor is the short wide pygidium. It may be noted, however, that the pygidium is not very different from that of *P. intermedius* Cobbold, to which *P. haywardi* seems on the whole to be most closely allied.

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